Integration of Optimal habit selection with DDA and SSRGA models for improved Microwave Radiative Transfer Simulations

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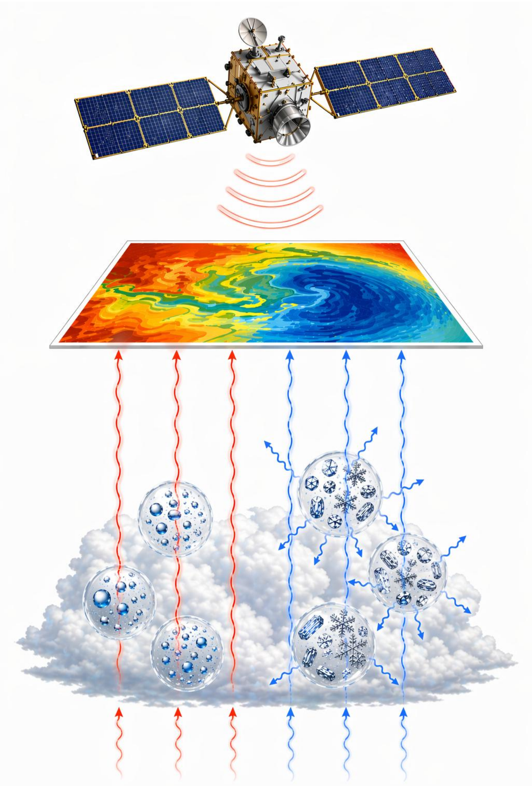
Radiative Transfer (RT) simulations

"Forward modeling (passive sensor)"



Cloud physical properties
- Mixing ratio, Number, density density, size, shape, … of hydrometeors

Bulk-scattering properties
- (Bulk) scattering coefficient
- (Bulk) Asymmetry parameter

Emission signatures
- Liquid, low-frequency channels

Scattering signatures
- Frozen, high-frequency channels

Microwave brightness temperatures (TBs)

Cloud microphysical (MP) assumptions

$$BSP = \int N(D) \cdot SSP(D)dD$$

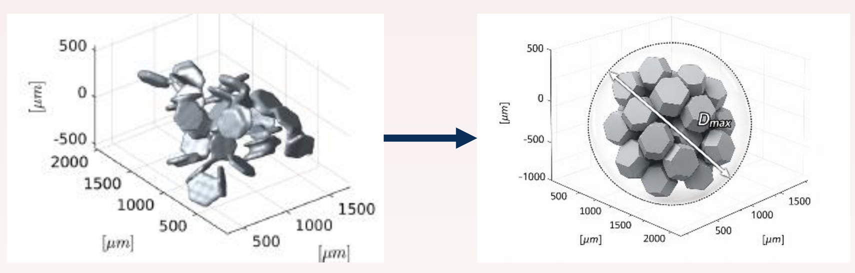
Bulk-Scattering Properties (BSPs) | Particle Size Distribution (PSDs) | Single-Scattering Properties (SSPs)

MP assumptions

- BSPs are defined by the combination of scattering behaviors of hydrometeor particles (SSPs) and their size distributions (PSDs) present in the unit volume.
- MP assumptions are simultaneously applied for PSDs and SSPs.
- Therefore, **realistic, consistent MP assumptions are required for improved RT simulations.**

Frozen particle shape assumptions

MIE

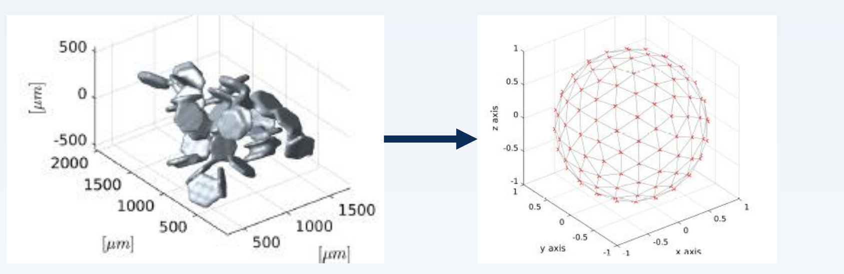


- SSPs: analytic solution of Maxwell's equation (Mie scattering).
- Nonspherical frozen particles are **approximated as spherical ice-air mixture** with equivalent major-axis diameter (D_{max}).
- **Oversimplified, unrealistic** shape assumption.

⇒ Scattering underestimation & Too much forward scattering.

*DDA

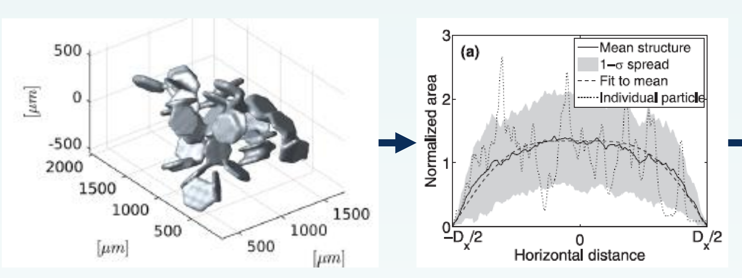
*Discrete Dipole Approximation (Draine and Flatau, 1994)



- SSPs: numerical solution of dipole interaction.
- Nonspherical frozen particles are **explicitly represented as high-resolution dipole mesh.**
- **Realistic shape assumption**
- SSPs and corresponding Densities are obtained from pre-calculated **ARTS database** *(Brath et al., 2020)*
- High computational cost => **limited particle habits** (17 crystals & 16 aggregates) provided.

*SSRGA

*Single-Scattering Rayleigh-Gans Approximation (Hogan et al., 2017)



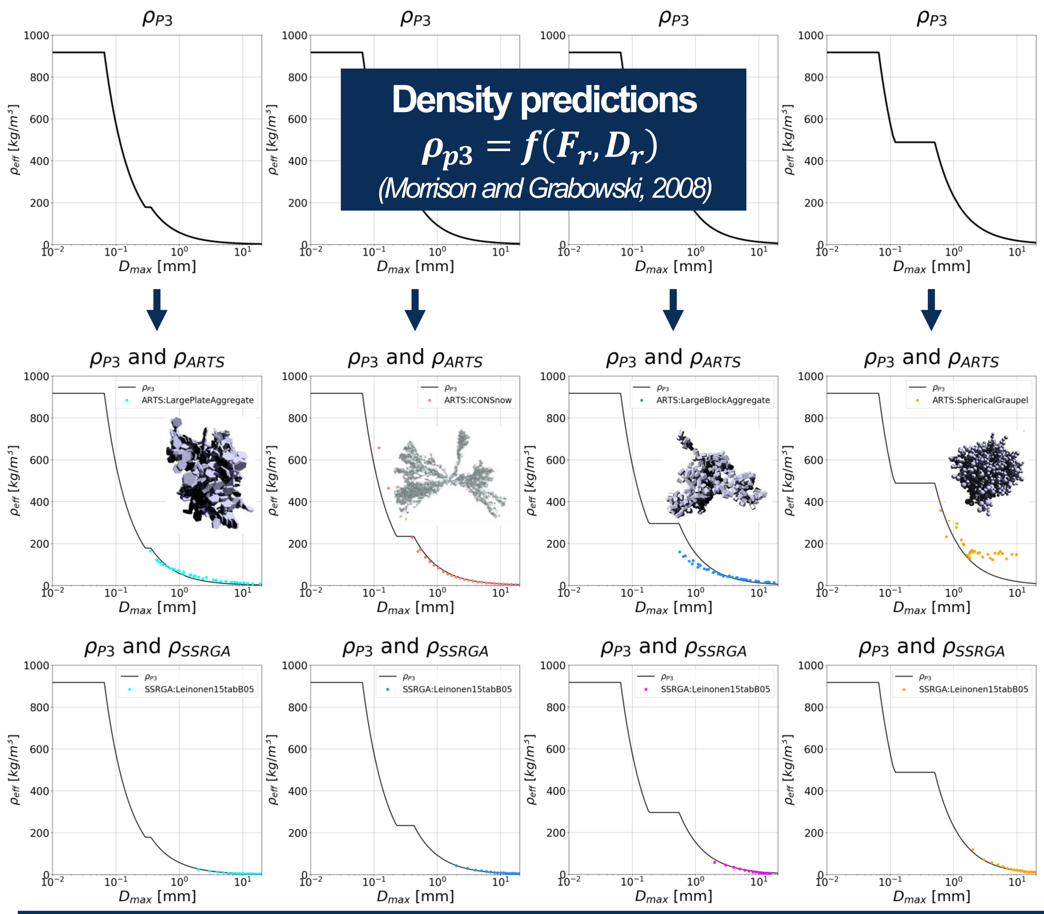
Shape factor
ϕ=f(SSRGA parameters)

- SSPs: analytic superposition of Rayleigh scattering *(Van de Hulst, 1957)*.
- Nonspherical frozen particles are **statistically parameterized to fractal structure represented by shape factor ϕ.**
- **Semi-realistic shape assumption**
- SSPs and corresponding Densities are obtained from pre-calculated **snowScatt database** *(Ori et al., 2021)*
- Computational efficiency => **diverse particle habits** (up to 94).

Optimal habit selection

WRF-P3 simulations
=> Prognosed riming properties
($^*F_r$, D_r)

$^*F_r$: Rime mass fraction
$^*D_r$: Rime mass density

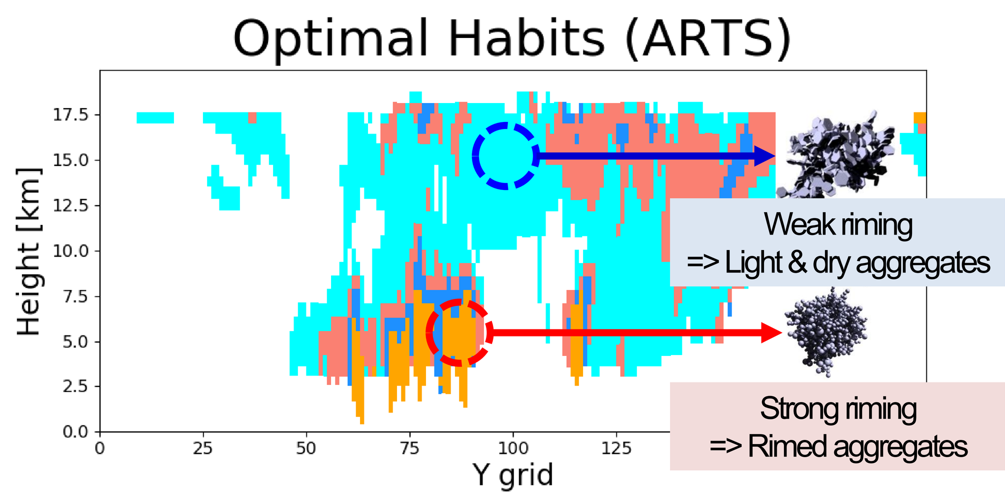


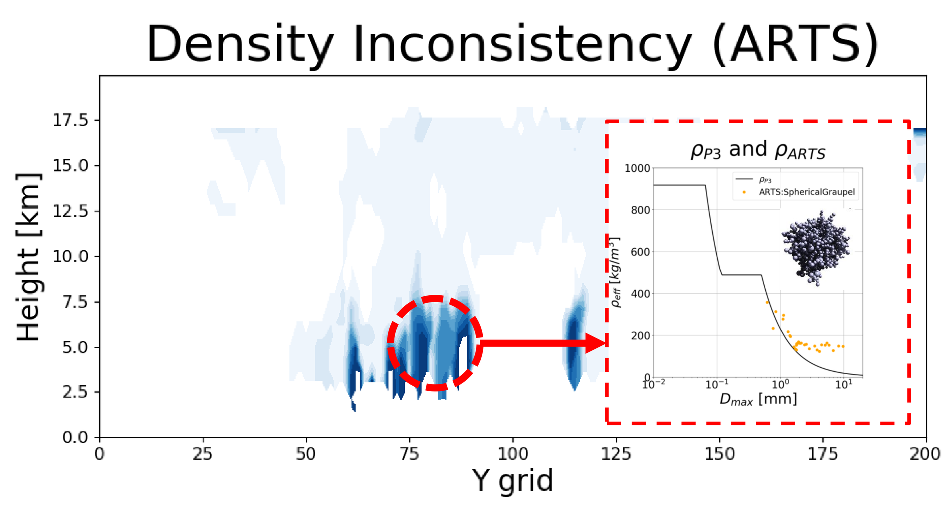
Assign optimal ARTS or SSRGA habit that best match ρ_{P3}
⇒ Use corresponding SSPs

- Represent **inhomogeneity** of natural frozen hydrometeors.
- Represent **DDA or SSRGA-based nonspherical particle scattering.**
- Maintain **microphysical consistency** between PSD (P3-based) and SSPs.

ARTS-OPT

ARTS database + Optimal habit

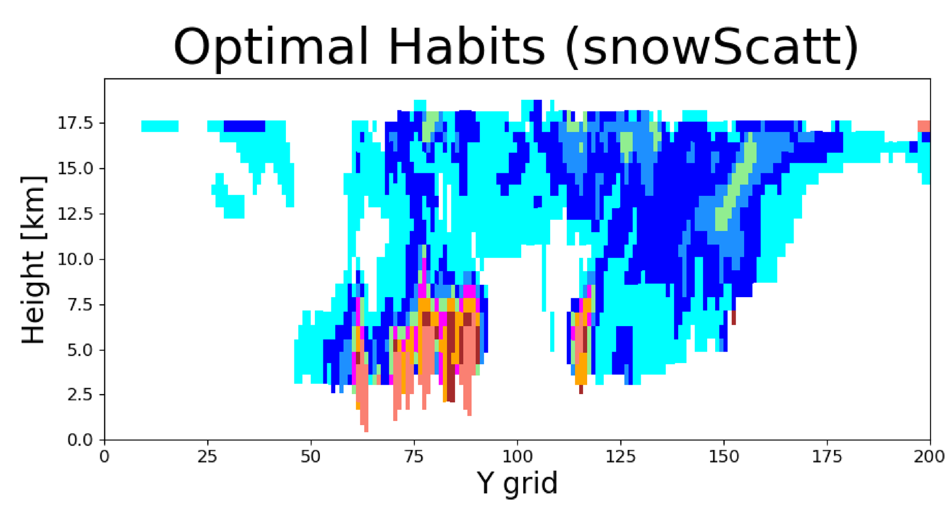


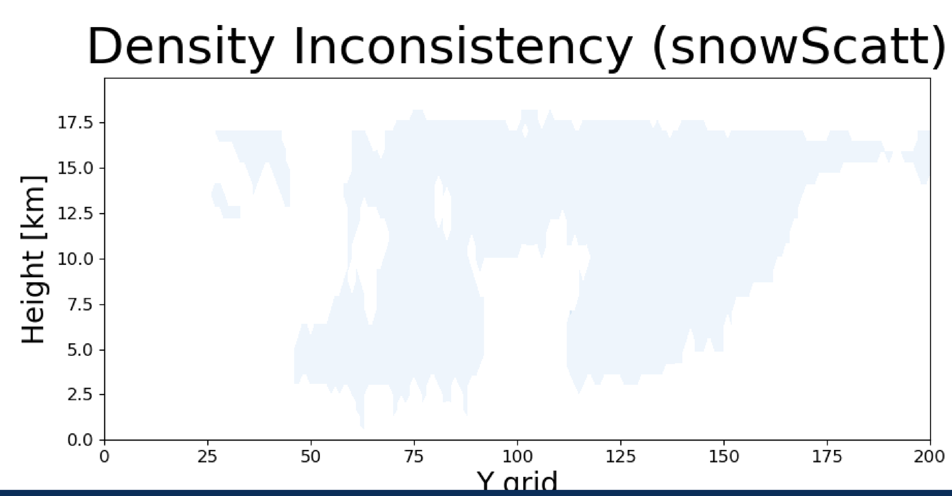


Limited number of ARTS habits
⇒ Non-representative rimed aggregates & Density inconsistency

SSRGA-OPT

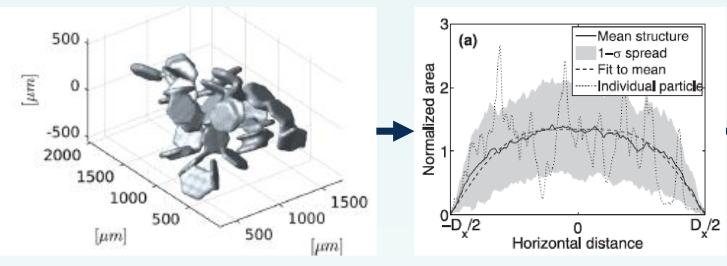
snowScatt database + Optimal habit





Diverse number of SSRGA habits
⇒ Improved inhomogeneity representation & Density consistency

SSRGA-PARA



Shape factor
ϕ=f(SSRGA parameters)

Density parameterization
ϕ=f(SSRGA parameters = f(Density)) *Maherndl et al. (2023)*

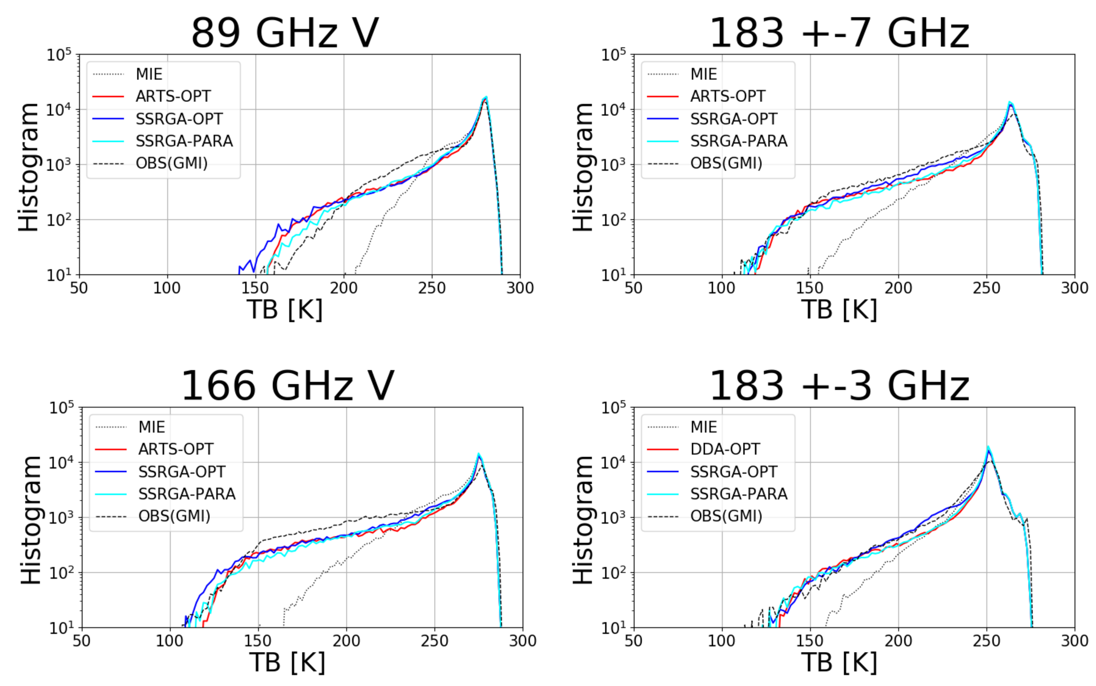
- SSPs: SSRGA-based.
- Nonspherical frozen particles are statistically parameterized to fractal structure represented by shape factor ϕ.
- ϕ is further **parameterized as function of particle density.**
- SSPs can be calculated **for any given density conditions without pre-calculated database, maintaining 100 % density consistency with P3.**
- Particle shape geometry is represented by **an artificial optimal habit corresponding to density.**

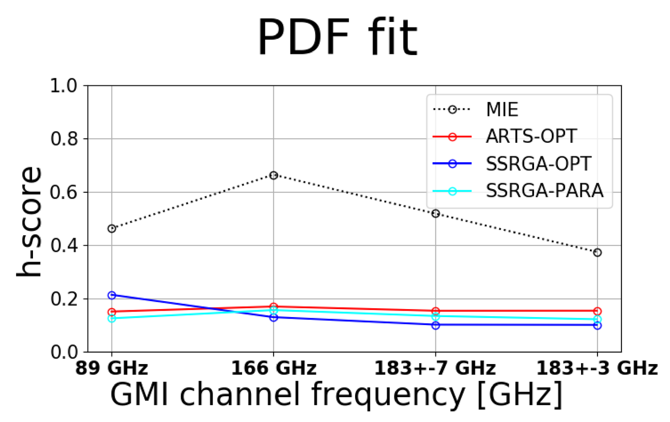
RT simulation performances

WRF-P3 simulations for 15-GPM GMI typhoon overpasses

RTM: MIE / ARTS-OPT / SSRGA-OPT / SSRGA-PARA

GPM GMI TBs (89-183 GHz)





- **MIE scattering underestimation resolved.**
- Three methods exhibit **similar RT simulation performances.**
- **SSRGA is beneficial for higher-frequency channels.**

Summary & Conclusions

❖ Realistic and microphysically consistent MP assumptions are essential for improving RT simulations.
❖ This study proposed three methods for representing microwave scattering by heterogeneous, nonspherical frozen hydrometeor particles.
❖ The proposed methods enable realistic scattering calculations corresponding to given atmospheric conditions while maintaining MP consistency throughout the RT simulation framework.
❖ All three methods consistently improved RT simulation performance.
❖ The SSRGA-based approaches provide the greater advantages in terms of MP consistency and simulation performance at higher-frequency channels.

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